Improved parameterization of marine ice dynamics and flow instabilities for simulation of the Austfonna ice cap using a large-scale ice sheet model

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Background

Austfonna

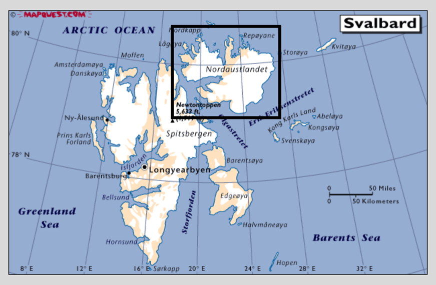
- dome-shaped and of compact size
- areal extent: 8120 km²
- max surface elevation: 800m
- mean/max ice thickness: 310/580
- 28 % of Austfonna grounded below sea level - up to 57% in case of three known surge-type basins

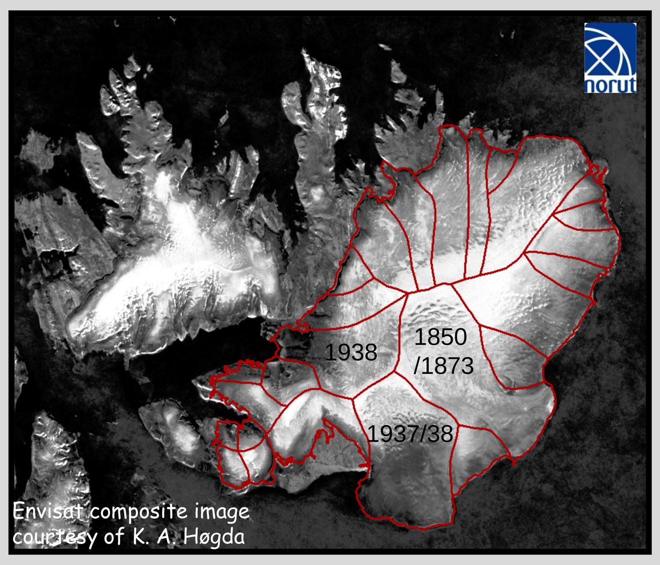
➢ applicable case study for numerical simulation of marine ice sheets

Motivation

- observed thickening in the interior and thinning at the margins[2,5]
- change in accumulation-ablation pattern or a build up towards renewed surge activity?[5,6,7]

➢ address surface processes and glacier dynamics by combining ongoing glacier observation with numerical modelling





The Austfonna ice cap and its location on Nordaustlandet in the northeast of Svalbard. The Envisat composite images is overlain by a basin mask giving the time of surge for the three known surge-type basins. The photo shows the marine ice margin of Basin-3.

Annual fieldwork since spring 2004

- surface mass balance and climate[1,2,3] (stakes, cores, 800-MHz GPR, AWSs)
- surface elevation changes[4], geometry
- (kinematic DGPS, 20-MHz GPR profiling)
- dynamics (continuous GPS)

➢ available data useful to set constrains on the model and to validate model results.

Numerical modelling

SICOPOLIS & model input

SImulation COde for POlythermal Ice Sheets[8]

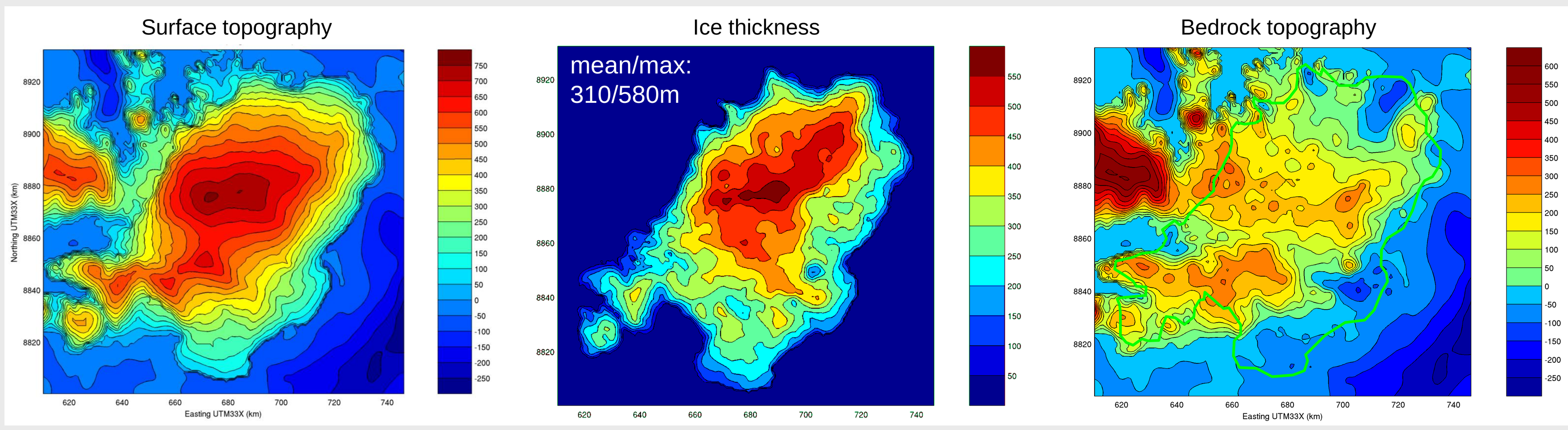
- shallow-ice approximation
- finite-difference method on a regular grid
- accounts for cold and temperate ice

Model input

- bedrock topography (present & relaxed)
- surface topography
- precipitation field
- surface air temperature
- geothermal heat flux
- sea level

Model output

- ice extent & thickness
- velocity field
- temperature field
- water content (temp ice)
- age of ice
- rebound of lithosphere



Marine ice margin

Real marine ice margin has a vertical calving front. Its position may be described using empirical formulae based on the flotation criterion

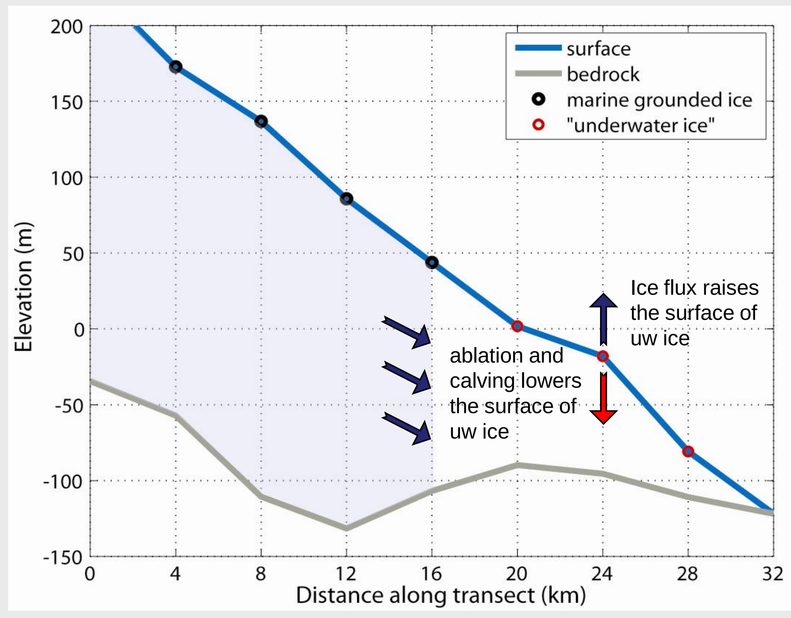
- works well for retreating margins, but prohibits marine advance
- (margin must move in one time step (0.1 – 1 yr) to next grid point (1,2,4 km) while overcoming the flotation criterion)

"Underwater (uw) ice"

- submarine ice allowed to form
- cumulative mechanism accounts for sub-grid position changes
- negative smb (low elevation) and calving Q_c proportional to local water depth D_w and ice thickness H_i to a certain power

$$Q_c = k_c D_w^k H_i^l$$

- balance of inflow and ice loss determines whether the local ice thickness exceeds or falls below flotation thickness



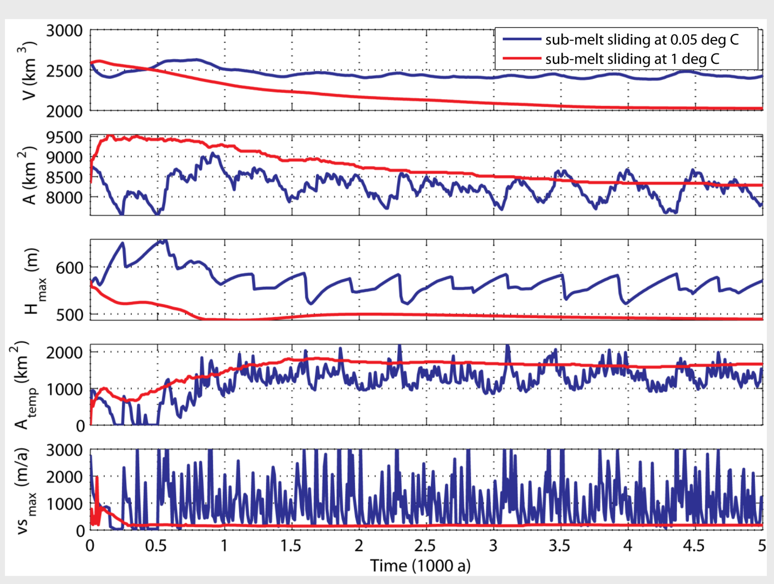
- post-processing may cut off uw ice for realistic extent of marine ice margin

Results – steady fast flow versus surge behavior

Weertman-type sliding law

$$v_b(T_b') = v_b(T_b' = 0) \times e^{T_b'/\gamma} = -C \frac{\tau_b^p}{N_b^q} \times e^{T_b'/\gamma}$$

- sub-melt sliding: from no-slip (frozen) to slip conditions (temperate base)
- reduced effective pressure N_b for marine grounded ice
- C, p and q may be specified for hard rock or soft sediment[9]



gamma slide = 1 ºC

p=3, q=2 everywhere

- smooth onset of sliding
- permanent and steady fast-flow features

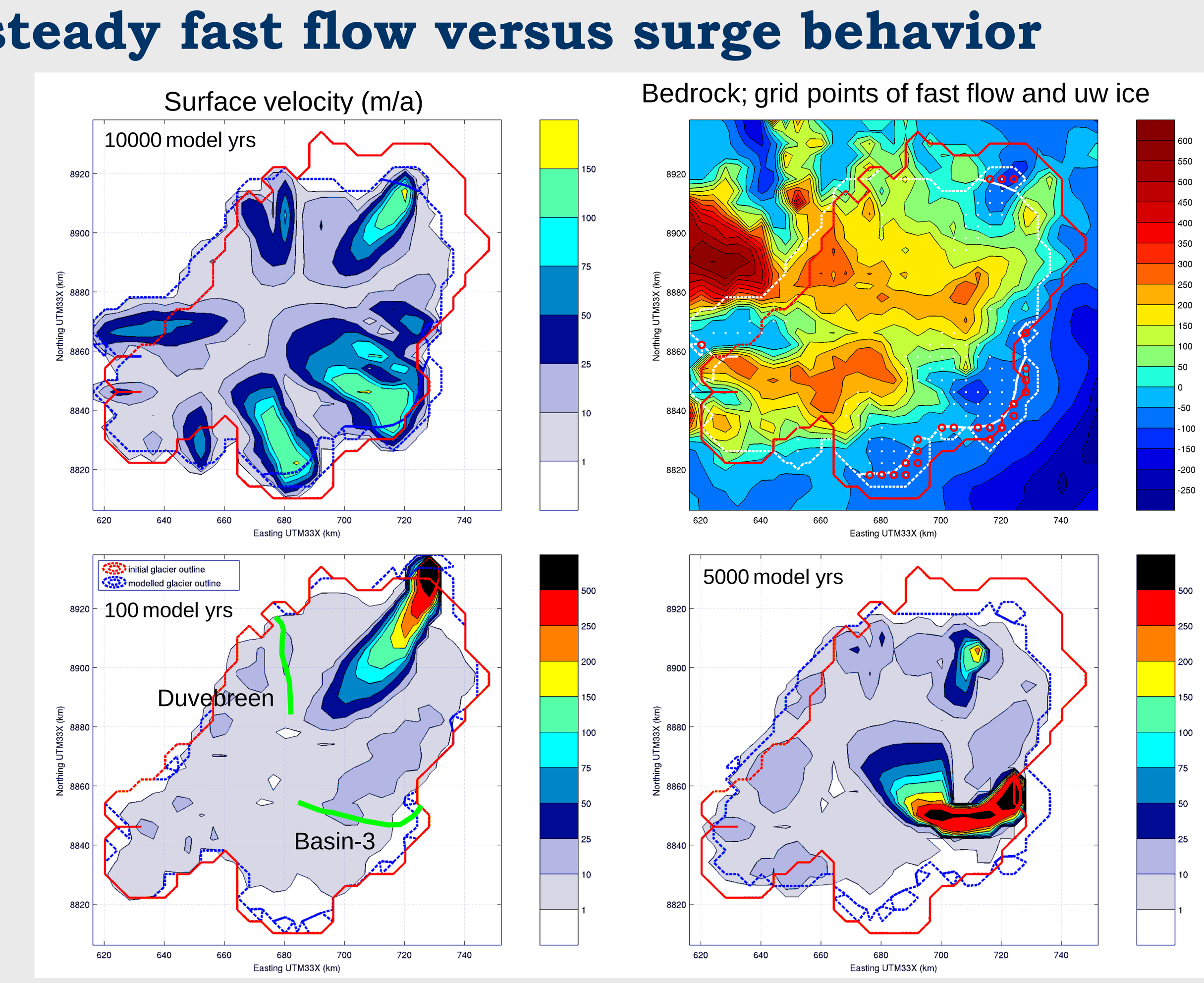
➢ thin ice cap of large extent

gamma slide = 0.05 ºC

p=3, q=2 for hard rock
p=1, q=0 for soft sediments

- abrupt onset of sliding
- individual basins periodically in active mode (surge)

➢ thick ice cap of small extent



Dynamic regime

- steady fast flow versus surge behavior in conjunction with marine ice dynamics strongly affect the steady-state geometry of Austfonna

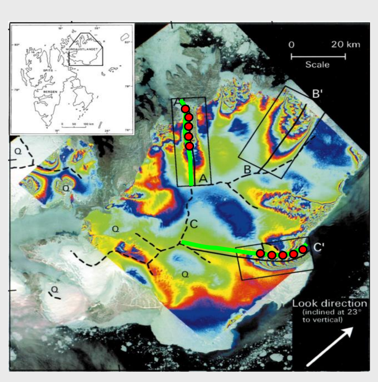
Sliding (enhanced for marine grounded ice)

- activated when temperate base develops during build-up phase (increased insulation)
- required to produce coincident present-day ice-cap volume and areal extent
- increased draw-down of ice thickness during active phase (enables surge behavior at present ice thickness)
- rigorous flow enhancement leads to drastic surges of regular occurrence

- uw ice allows (re-) advance of marine margins
- fast flow occurs despite the lack of considerable temperate ice volumes

Observations

Dynamics

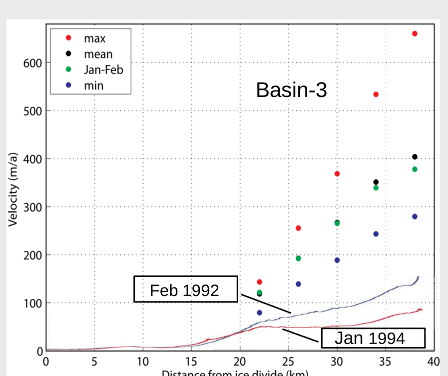


ERS-1/2 SAR interferogram superimposed on Landsat image (modified from Dowdeswell,et al., 1999)

- surface velocity measurements until recently restricted to winter snapshots of mid 1990s[6,11]

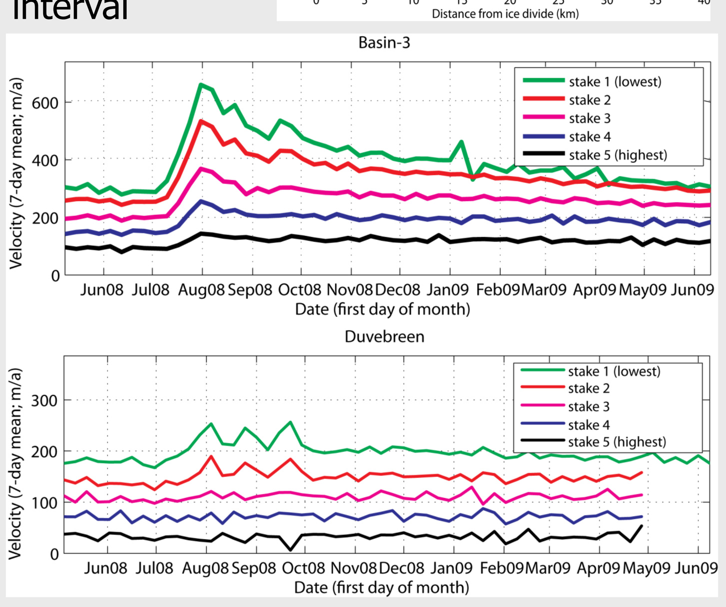
➢ slow moving ice cap (<10 m/a) interrputed by fast flow units (>100 m/a)

- new stake networks on Basin-3 and Duvebreen
- 5 stakes each, along central flow line
- equipped with GPS receivers (IMAU, Utrecht) for continuous positioning at 1h interval



velocity record spans one annual cycle:

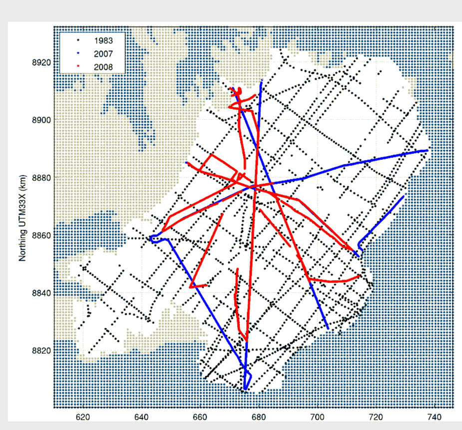
- linear increase downstream with annual means ranging from 40 to 200 m/a for Duvebreen and 110 to 400 m/a for Basin-3
- values in Jan/Feb 2009 are 2-3 times larger than in mid 1990s
- speed-up during July, most pronounced at lowermost stake (>2-fold for Basin-3), decreasing amplitude and slight delay upstream; less pronounced on Duvebreen
- slow decrease from max. values until next summer



Thermal regime

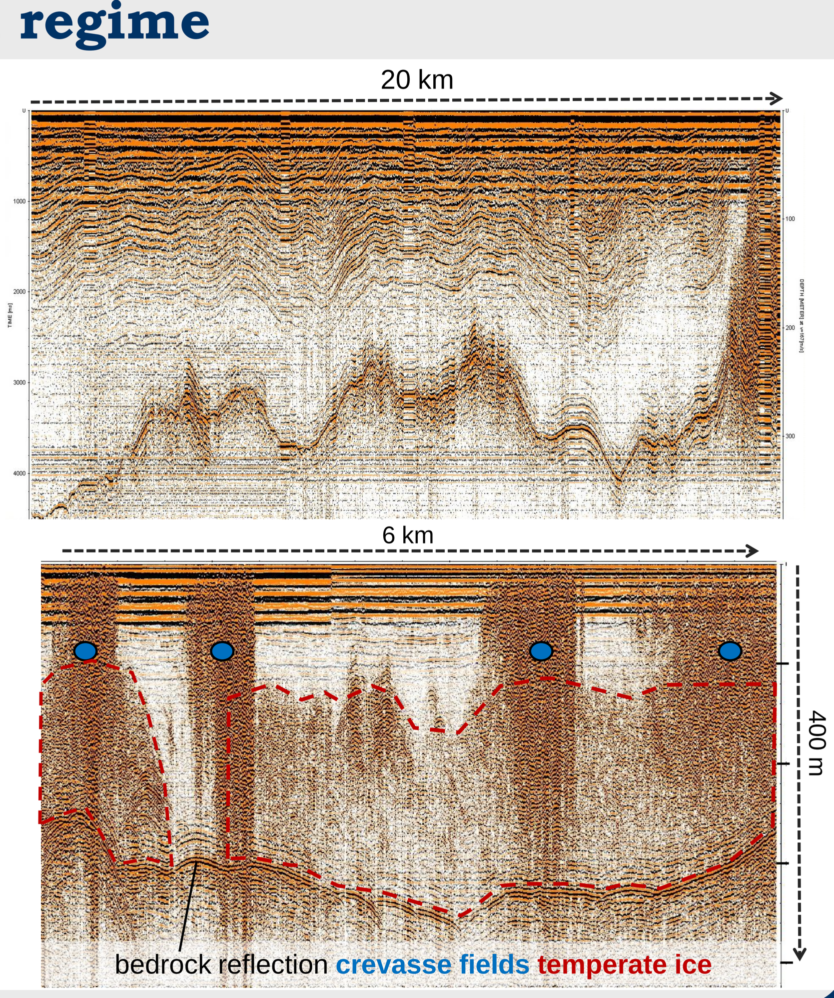
Low-frequency GPR (20 MHz)

- internal reflection horizons down to 200 m depth originate from volcanic ash layers
- absence of reflections below 200 m along most transects indicate cold ice
- exception: lower reaches of Duvebreen crevasses route surface meltwater into glacier (direct warming and latent heat release)



GPR (2008, red) and airborne RES (2007, blue) for update and validation of RES survey in 1983-84 (black) [10]

Crevasse field on lower Duvebreen during late summer



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Acknowledgements

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